3rd Steinmüller Engineering Conference 2019

Application of CFD for optimization of critical Waste Heat Boilers

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Rely on good experience with Steinmüller engineering

The Engineers Company
1. Introduction
2. Thermodynamic model
3. Challenges of thermal design
4. CFD investigations
5. Derived solutions
6. Executed projects
7. Summary
1. Introduction - Synthesis gas generation

- Natural gas
- Steam
- Primary Reformer
- Convection Bank
- Secondary Reformer
- Air
- WHB
- HT CO-Shift
- LT CO-Shift
- CO₂ Scrubber
- Methanation

Temperature profile:
- Natural Gas
- Primary Reformer
- Secondary Reformer
- Waste Heat Boiler
- HT-CO Shift
- LT-CO Shift
- CO₂ removal
- Methanation

Temperature / °C

0 200 400 600 800 1000

IHI GROUP
1. Introduction - Waste Heat Boiler / Process Gas Cooler

<table>
<thead>
<tr>
<th>Project design data</th>
<th>Gas side</th>
<th>Water / Steam</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature @ inlet</td>
<td>900 - 1050 °C</td>
<td></td>
</tr>
<tr>
<td>Temperature @ outlet</td>
<td>330 - 380 °C</td>
<td>310 - 324 °C</td>
</tr>
<tr>
<td>Pressure</td>
<td>30 - 35 barₐ</td>
<td>100 - 120 barₐ</td>
</tr>
<tr>
<td>Hydrogen content</td>
<td>30 %</td>
<td></td>
</tr>
</tbody>
</table>

- Two design types:
  - Fire tube – syngas on tube side
  - Water tube – syngas on shell side

- Gas outlet temperature is critical for running time of CO shift reaction

- Most critical heat exchanger in Ammonia / Methanol / Hydrogen plants
1. Introduction – Project: Sluiskil C E301 Retrofit

**Initial Design**

- **Existing WHB with poor performance:**
  - low heating surface efficiency
  - too high gas outlet temperature
  - High wear of the CO catalyst downstream WHB
  - Limitation of the plant productivity

- **CFD analysis indicated**
  - Large circumferential bypass (around the tube bundle)
  - High bypass through the gap between the baffles and refractory
  - Poor gas flow distribution
1. Introduction – Project: Sluiskil C E301 Retrofit

**Optimized Design**

- Significant reduction of the gas outlet temperature at full load of the plant
- Reduction of the pressure loss on gas side
  - Higher plant efficiency
- Original dimensions and interfaces remain unchanged

<table>
<thead>
<tr>
<th></th>
<th>Before retrofit</th>
<th>Calculated values</th>
<th>After retrofit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inlet temperature °C</td>
<td>890</td>
<td></td>
<td>890</td>
</tr>
<tr>
<td>Outlet temperature °C</td>
<td>351</td>
<td>328</td>
<td>&lt; 328</td>
</tr>
<tr>
<td>Pressure drop mbar</td>
<td>350</td>
<td>310</td>
<td>300</td>
</tr>
<tr>
<td>No. of passes</td>
<td>6</td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>No. of U-tubes</td>
<td>474</td>
<td></td>
<td>572</td>
</tr>
<tr>
<td>Steam temperature °C</td>
<td>313</td>
<td></td>
<td>313</td>
</tr>
<tr>
<td>Steam production t/h</td>
<td>115</td>
<td></td>
<td>119,6</td>
</tr>
</tbody>
</table>
2. Thermodynamic model

DimBo® model calculates:

- Heat and mass balance
- Heat fluxes
- Media temperatures
- Steam content
- Gas side pressure drop
- Water/steam side pressure drop
- Material temperatures
- Heat absorption across the bundle
2. Thermodynamic model

Waste Heat Boiler

1. Pass

2. Pass

3. Pass

4. Pass

5. Pass

GAS INLET

GAS OUTLET

BOILER WATER

WATER / STEAM MIXTURE

GAS BYPASS

(GAS BYPASS (PROCESS)

GAS BYPASS

(OUTLET TEMP. CONTROL

GAS INLET

GAS OUTLET

WATER / STEAM MIXTURE

BOILER WATER

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3. Challenges of thermal design

- For retrofit projects footprint, interfaces and loads shall be maintained
- Gas bypasses affect efficiency:
  1. Through the gap between the refractory and the baffles
  2. Through slightly oversized holes for the tubes in the baffles
  3. Around the bundle (circumferential bypass)
- Gas flow distribution affects efficiency
2. Thermodynamic model / CFD interfaces

**DimBo®**

1. Pre-Design of the WHB

   - Heat absorption across the bundle

2. Final design of the WBH

   - Heating surface efficiency
   - Bypass flows

   - Heat absorption across the bundle

**CFD:**

1. Basis Simulation

2. Optimization of gas flow distribution

3. Estimation of internal gas bypass

   - Material temperature of the baffles
   - Pressure loss gas side

4. Final Simulation

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4. CFD investigation – model setup

- Heating surface bundle is split in sections corresponding to thermodynamic model → 5 Passes, with 4 sections per pass
- Heat transfer within each section is calculated by means of thermodynamic model
- Bundle and perforated plates are modelled as porous volumes
- Porous areas defined with 3D restriction factors
- Realizable k – ε model
- Cell Reynolds number limited to 15
4. CFD investigation – modelling of circumferential bypass

- Gas flow tends to bypass bundle on circumferential section
- Sealing strips prevent gas bypasses across bundle
- Efficiency and remaining flow estimated by 2D CFD model
4. CFD investigation – modelling gas distribution

Findings of Basis simulation:
- Poor flow distribution
- Low efficiency of the heating surface → $T_{\text{GasOut}}$ too high
- Uneven gas flow → too high local heat flux / higher pressure loss

Optimization of gas flow leads to:
- Even flow distribution in 1st pass
- Optimal heat absorption within the bundle
- Reduction of the heat flux peaks
- Reduction of the pressure loss

Perforated plates & baffle extensions
4. CFD investigation – modelling of baffle temperatures

- Prediction of baffle temperatures by means of CFD
- Temperature distribution of each baffle
- Determination of the thermal expansion of each baffle allows to minimize the gap between baffle and refractory
- Reduction of gas bypass through the gap from one pass to next one
4. CFD investigation – gas side pressure drop

- Calculation of the gas side pressure loss considering:
  - Temperature effect
  - 3D flow distribution
  - Local flow acceleration

- $\Delta p$ calculated by CFD is used to define the gas bypass flow from pass to pass
## 5. Solutions derived from CFD model

### Causes for poor performance

<table>
<thead>
<tr>
<th>Causes for poor performance</th>
<th>Optimization measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Circumferential bypass (around the bundle)</td>
<td>• Positioning of sealing strips</td>
</tr>
</tbody>
</table>
| • Baffle bypass (through the gap between baffle and refractory) | • Baffle temperatures  
• Individual baffle design to reduce gap |
| • Non-uniform Gas distribution | • Perforated plates  
• Baffle extensions |
### 6. Executed references

<table>
<thead>
<tr>
<th>Plant</th>
<th>Location</th>
<th>Steam production</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ferrara</td>
<td>Ferrara, Italy</td>
<td>112.000 kg/h</td>
</tr>
<tr>
<td>YTL - E2016</td>
<td>Point Lisas, Trinidad</td>
<td>200.000 kg/h</td>
</tr>
<tr>
<td>YAT - E904B</td>
<td>Point Lisas, Trinidad</td>
<td>156.000 kg/h</td>
</tr>
<tr>
<td>SLU C - E301</td>
<td>Sluiskil, Netherlands</td>
<td>119.600 kg/h</td>
</tr>
</tbody>
</table>
7. Summary

- CFD is an essential tool, which allows a high-grade precise design of the components
- Combination of thermodynamic design tool and CFD as a best practice approach
- Significant increase of the equipment performance and efficiency within the limited installation space (e.g. retrofit projects)
- The obtained investigation results are confirmed by the executed projects
Thank you for your attention.